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POSSIBILITIES FOR IMPROVING THE CONVENTIONAL INSTRUMENT LANDING SYSTEM (ILS)

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16. Abstract

The possibility of improving conventional instrument landing systems by supressing interference from reflected radiation is discussed. The two methods considered are the analysis of interference by additional amplitude and frequency modulation, and the exclusion of interference by quotient formation or circular polarization.

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SPECIAL RESEARCH AREA--FLIGHT GUIDANCE

POSSIBILITIES OF IMPROVING CONVENTIONAL INSTRUMENT LANDING SYSTSMS (ILS)

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POSSIBILITIES OF IMPROVING CONVENTIONAL INSTRUMENT LANDING SYSTEMS (ILS) /2*

1. Possible Approaches

Two uncontrollable defects appear in the instrument landing procedures now installed as the most important means of control (ILS-Cat. II/III), which were first developed in 1930's years as guidance aids. Landing course and glide path are disturbed by interference resulting from multi-path broadcasting and in addition, the glide path is also influenced by changes in the reflecting properties of the ground.

*Numbers in the margin indicate pagination in the foreign text.

One possibility of improving the conventional instrument landing system is to prevent the influencing of the measurement results by the reflected radiation at the point of reception, that is, on board the aircraft, and to utilize only the direct radiation. Since there is always present at the receiving point only the resulting interference field corresponding to the superimposition of the direct and reflected radiation, the problem to be solved consists, first, of determining from the interference field the portion of direct and reflected radiation, in both strength and phase, so that the reflected radiation can be made ineffective by compensation.

For analysis of the interference field, two principal different methods can be described. In one case, by modification of ground equipment and on-board equipment, the conventional ILS /3
installations are either supplied with additional information which makes possible the resolution of the resulting signal after reception into direct and reflected radiation, or procedures are employed which serve to exclude the effect of the reflected radiation. In the other case, the analysis of the interference field is carried out with completely unaltered ground and on-board installations by additional antennae on board, and the separate evaluation of the received signals of a single dipole, according to strength and phase, is carried out in an additional on-board apparatus. While in the first case, attention must be paid at each step to assure that compatibility is retained, this challenge is met in the second case without further ado, since only those users who are interested in an undistorted evaluation must install additional equipment.

Both cases were examined thoroughly at the Technical University of Brunswick in the Special Research Area "Flight Guidance." We consider it sensible, with full acknowledgement of the limits and the unavoidable defects of ILS, to explore all imaginable approaches for the improvement of the conventional instrument landing system within the realm of physical possibility, since the ILS utilized up to the year 1985 certainly will be in operation for a period of 15 more years, and we do not have to deal with a short-term introduction of new approach procedures. For the judgment of today's landing system, the question should be clarified whether and by what means an improvement of the ILS is possible. Only after the conclusion of the planned measures will it be possible to distinguish to what extent and at what expense conventional ILS can be improved. If in this report, the unusual path is chosen of reporting only on approaches and partial results, then on that account there should be nothing more to improve in ILS, which is often asserted nowadays. We see our task in either refuting or proving this assertion. Corresponding to the status of our work, we will report here only on the first category of possible improvements of ILS in which either the interference field is analyzed by the introduction of additional amplitude and frequency modulation, or the influence of the reflected radiation is excluded, either by forming the corresponding quotient in place of the difference of the degrees of modulation (DDM) or by changing over to circular polarization. /3

2. Possibilities in the Case of Interference Disturbances from Multi-Path Broadcasting

As is well known, interference disturbances falsify the landing course as much as 12 km before the touchdown point (Fig. 1). In this case it is of special importance in practice that on board the aircraft the commencement of the interference is not recognizable, so that the aircraft follows the initial slow changes of the landing course until this is no longer possible for the Autopilot on further approach, for example, above 0.1 Hz; at that point the directional information becomes completely lost. A first step towards the improvement of the evaluation of on-board information is, therefore, detection of interference. Of very much greater importance, however, is suppression of interference, in order to obtain a useful on-board indication even in the interference field. According to our experience, interference disturbances are to be reckoned with the landing course as well as in the glide path.

2.1 Interference Detection /4

For detection of interference at the point of reception, the first appearance of the reflected radiation must immediately be established. While the indication criterion suitable for this is given directly by impulse sampling systems through the time delay difference, it can be obtained, as Fig. 2 shows, by the continuous reflection of the ILS through the turning of the guide diagram of the landing course. There is produced in this way additional amplitude modulation, changeable with position and time, whose time of arrival at the point of reception depends on the different angle of incidence of the direct beam 1 and reflected ray 2. As long as no reflection is present, the usual constant DDM-indication results, as the dashed line in Fig. 3 shows. If reflection takes place, there results DDM time delay shown in Fig. 3 by the drawn-out line, which exhibits indicator deviation for recognition of the disturbance, with a period of $T_s = 1/f_s$, and a frequency f_s.

2.2 Suppression of Interference

For suppression of the interference the reflected wave must first be determined in both strength and phase by analysis of the resultant field at the point of reception. In order to obtain the necessary determining equations, the ground transmitters must have an additional frequency modulation superimposed. The indication of the reflected wave is given by the resulting changes of amplitude and frequency.

Fig. 4 shows the principal relationship in its simplest form /5
in the case of gliding, where different angular velocities are superimposed on the indicator. It is important for the interference analysis that periodic frequency changes occur, along with the known amplitude oscillations, in the course of which peaks of interference appear which are dependent on the amplitude relationship these can be displayed as the output voltage of an FM discriminator. In the chart shown in Fig. 5 of the instantaneous frequency on the superimposition of two frequency-modulated oscillating signals corresponding to the direct and reflected ILS signal, the determination of the amplitude, upper frequency (ψ_t), and lower frequency (ψ_t) phase shift of the reflected beam is possible from the number Z of the interference peaks the amplitude $\Omega_{s_{max}}$ of the interference peaks and from the introduction of the maximum possible number Z_{max} of interference peaks at the lower frequency phase shift $\phi_n = 180°$. For the determination of the three unknowns in the resulting frequency curve, the three equations

$$Z = f(\varphi_n, \varphi_t); \quad \frac{\Omega_{smax}}{\Omega_m} = f(\varphi_n, A);$$

$$Z = Z_{max} \text{ für } \varphi_n = 180^{\circ} \text{ ausgewertet,}$$

are evaluated, in which Ω_m is the frequency swing of the superimposed frequency modulation, and A is the amplitude ratio of the direct and reflected signals.

3. Elimination of Variable Reflections from the Ground That Influence the Glide Path /6

Since, as is well known, in the evaluation of glide path information, the vertical course diagram must draw upon the reflection from the earth which is known to occur (Fig. 6), changes of the reflection properties of the earth from rain and snowfall necessarily influence the measurement results. A removal of this interference is possible by changing over to arrangements in which the influence of the reflected radiation is excluded. This may be done by procedures in which either the quotient of the comparison signals is formed instead of the DDM, or circular polarization is used.

3.1 Exclusion of the Influence of the Earth by Quotient Formation

For fixing the glide path independently from the properties of the ground, as Fig. 7 shows, two comparison antennae with large (outer dipole pair) and small (inner dipole pair) are brought together with a common center of gravity $S_a = S_i = S$. Since both comparison antennae have the same earth diagram $C_{Erd}(\gamma)$ at the same height of center point, changes in the influence of the ground affect both comparison antennae in the same way on the vertical diagram $C_a(\gamma)$ and $C_i(\gamma)$, since the specific diagrams (free space diagrams) $C_{aEigen}(\gamma)$ and $C_{iEigen}(\gamma)$ are multiplied by the same factor $C_{Erd}(\gamma)$. This gives

$$C_a(\gamma) = C_{aEigen}(\gamma) \cdot C_{Erd}(\gamma)$$
$$C_i(\gamma) = C_{iEigen}(\gamma) \cdot C_{Erd}(\gamma).$$

If now on board, the quotient $O(\gamma)$ of the received signals is /7
formed, then the value of the existing influence of the ground is obtained, for each single antenna.

$$Q(\gamma) = \frac{C_a(\gamma)}{C_i(\gamma)} = \frac{C_{aEigen}(\gamma)}{C_{iEigen}(\gamma)}$$

The quotient of the comparison voltages $O(\gamma)$ is therefore determined exclusively by the specific diagrams of the antennae.

If the dipole pairs set forth in Fig. 7 are fed out of phase, then this arrangement corresponds to the glide path antenna of today, if one imagines that the miror image of today's antenna is a constituent of the built-up antenna.

For the exclusion of the influence of the ground, the common center of gravity of both comparison antennae is necessary but is not in itself a sufficient condition. Since, as Fig. 8 shows, direct and reflected beams always impinge at the point of reception, the quotients of the direct wave Q_d and the reflected wave Q_r must also correspond so that when they are superimposed at the point of reception, they do not falsify the quotients determined by the specific diagrams. The condition $Q_r = Q_d$ is fulfilled if the quotient $Q(\gamma)$ changes symmetrically to the axis of the antennae; in the course diagram given in Fig. 7 the symmetry condition is met. For this the assumption is still necessary that in the reflection at the ground, the permissible changes of the reflection factor remain constant within the width of the point of arrival.

3.2 Exclusion of the Influence of the Ground by Circular Polarization /8

In circular polarization, the reflected radiation at the earth experiences a reversal of the direction of rotation of the plane of polarization because of the different reflection factors of the horizontal and vertical polarized components of the wave. This event is shown schematically in Fig. 9. If a receiving antenna at the point of reception P is arranged as a polarization filter for the direction of rotation of the direct incoming wave, then the wave reflected from the ground provides no received voltage because of its oppositely oriented rotational direction, so that the reflection from the ground does not enter into the measurement.

In elliptical polarization of the reflected wave, the portion in the direction of rotation of the direct radiation yields a residual error F_F, that is dependent on the reflection conditions on the ground, on the height h of the antenna over the earth, on the wavelength λ, and on the angle of incidence γ. As Fig. 10 shows, for the ILS glidepath angle $\gamma = 3°$, the residual error F_F disappears at a corresponding selection of height of installation h/λ. From Fig. 11, in which the optimal height of installation h_{opt}/λ to be chosen for disappearance of the residual error is plotted against on the angle of incidence γ for different reflection factors at the ground, it is to be noted that practically even at extreme dryness and at extreme humidity of the ground, the height of the antenna to be chosen for $\gamma = 3°$ remains almost constant at $h_{opt}/\lambda = 1.8$, and therefore the residual error from elliptical polarization of the reflected beam for all weather conditions is negligibly small.

4. Outlook

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The advantages set forth in the work we have started, and the limits of the possibilities of improvements for conventional ILS, should be verified by simulation of ILS interference fields, and by measurements on a glidepath installation set up according to the quotient procedure. We hope to be able to report on this in a short time, drawing on the analysis of the interference field by several on-board receiving antennae described in the Introduction.

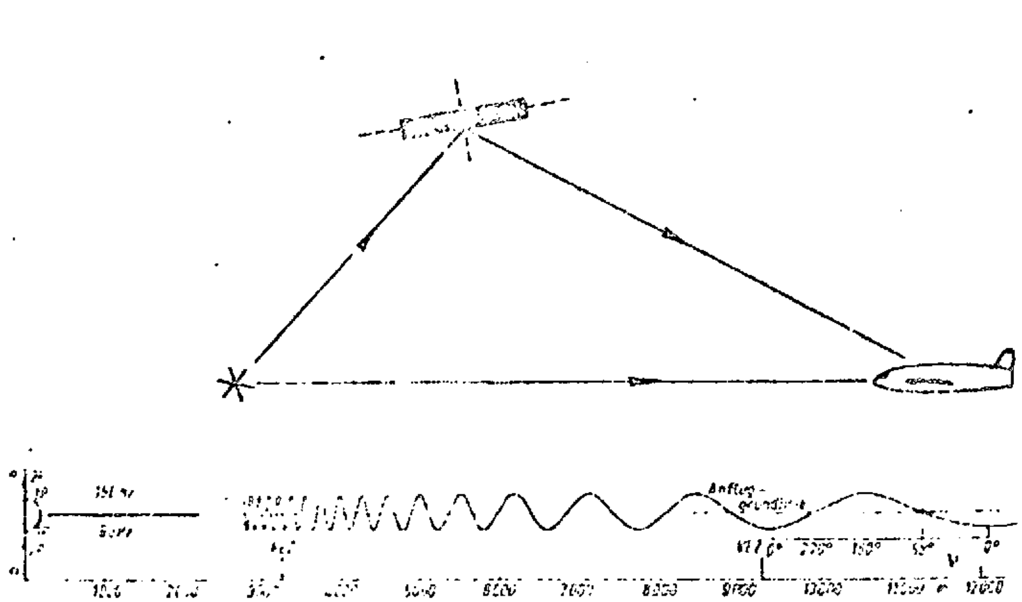

Fig. 1. Deviations of the vertical indicator of the cross pointer instrument in the approach to the ground approach line. $\alpha = f(r)$ for $\theta_1 = 0$, from K. Barner, Influence of Reflections on the quality of the landing course.

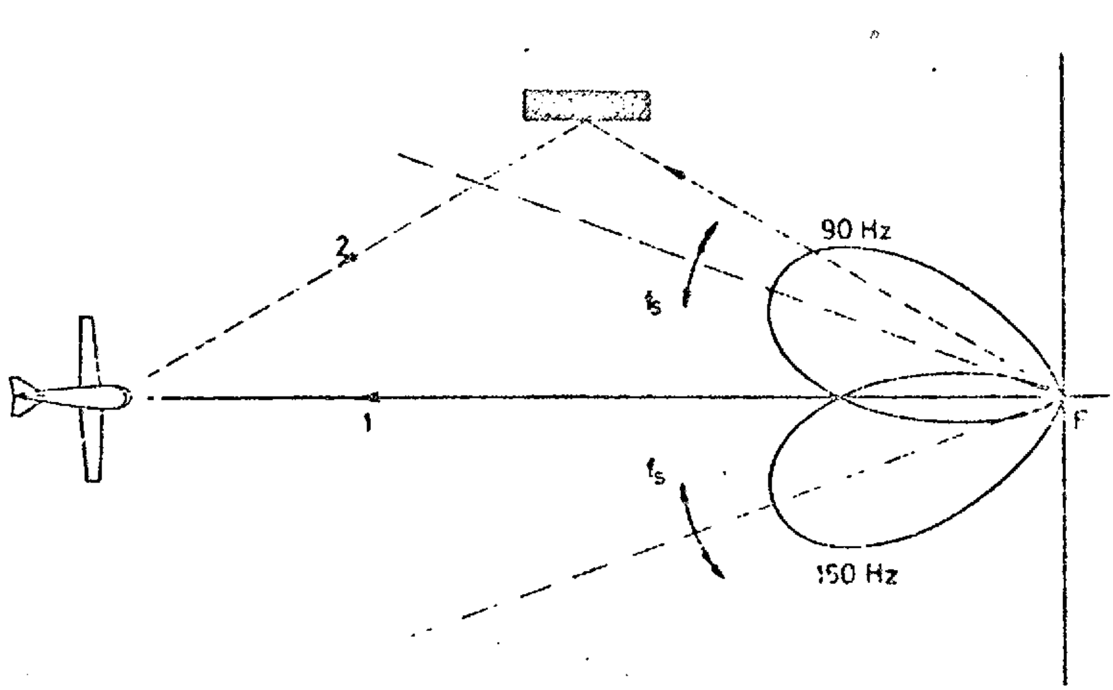

Fig. 2. Schematic illustration of the opposed variation of the 90 Hz and 150 Hz [illegible].

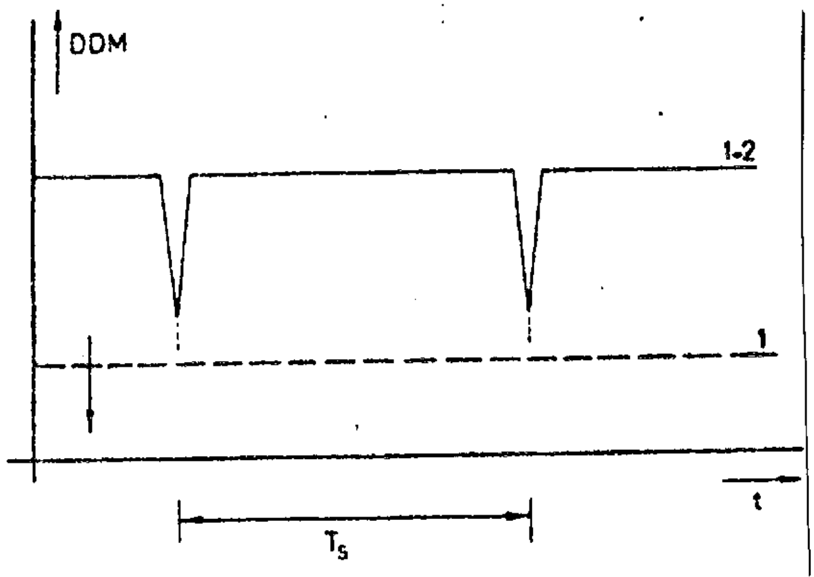

Fig. 3. DDM indication on approach. Dashed line at undisturbed approach: drawn-out line with indication deviations of period $T_s = 1/f_s$ on the occurrence of reflected radiation.

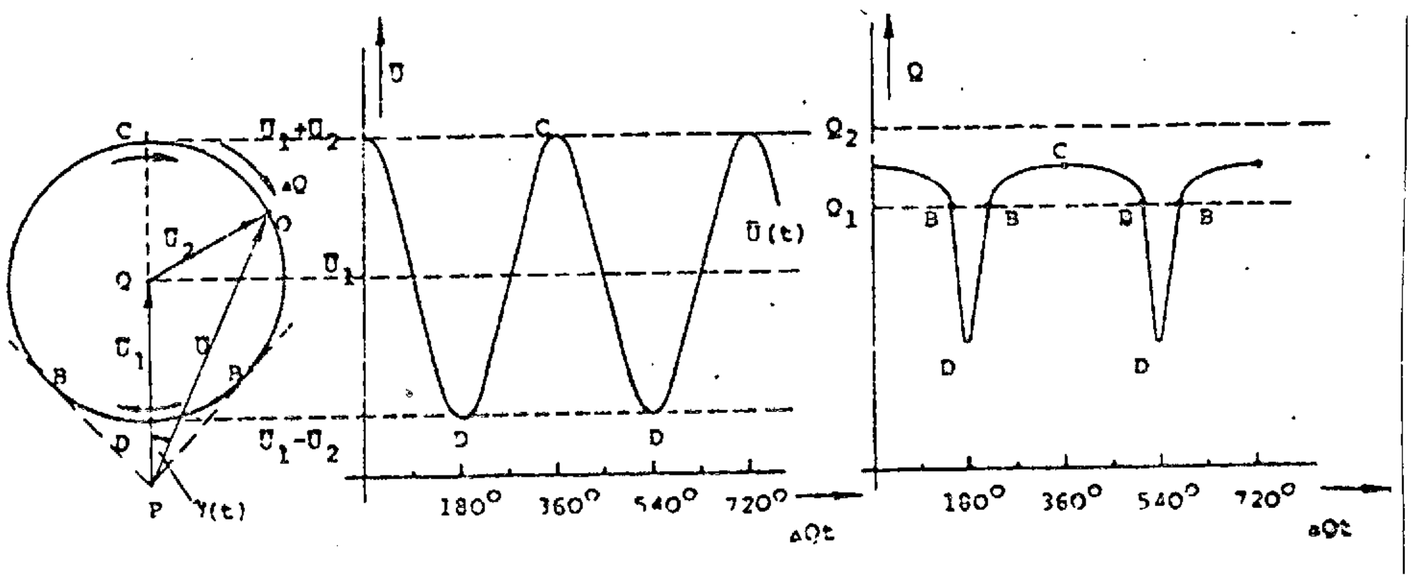

Fig. 4. Indicator diagram and amplitude and frequency changes with time of the resulting oscillation for A < 1.

$$(11a)\quad \Omega(t) = \Omega_t + \Omega_m \cos\omega t + \frac{\Omega_m\left[\cos(\omega t+\varphi_n) - \cos\omega t\right]\left[A^2 + A\cos\left\{\varphi_t + \frac{\Omega_m}{\omega}\left(\sin(\omega t+\varphi_n) - \sin\omega t\right)\right\}\right]}{1 + A^2 + 2A\cos\left\{\varphi_t + \frac{\Omega_m}{\omega}\left(\sin(\omega t+\varphi_n) - \sin\omega t\right)\right\}}$$

$$(11b)\quad \frac{\omega(t)}{\Omega_m} = \cos\omega t + \frac{\left[\cos(\omega t+\varphi_n) - \cos\omega t\right]\left[A^2 + A\cos\left\{\varphi_t + \frac{\Omega_m}{\omega}\left(\sin(\omega t+\varphi_n) - \sin\omega t\right)\right\}\right]}{1 + A^2 + 2A\cos\left\{\varphi_t + \frac{\Omega_m}{\omega}\left(\sin(\omega t+\varphi_n) - \sin\omega t\right)\right\}}$$

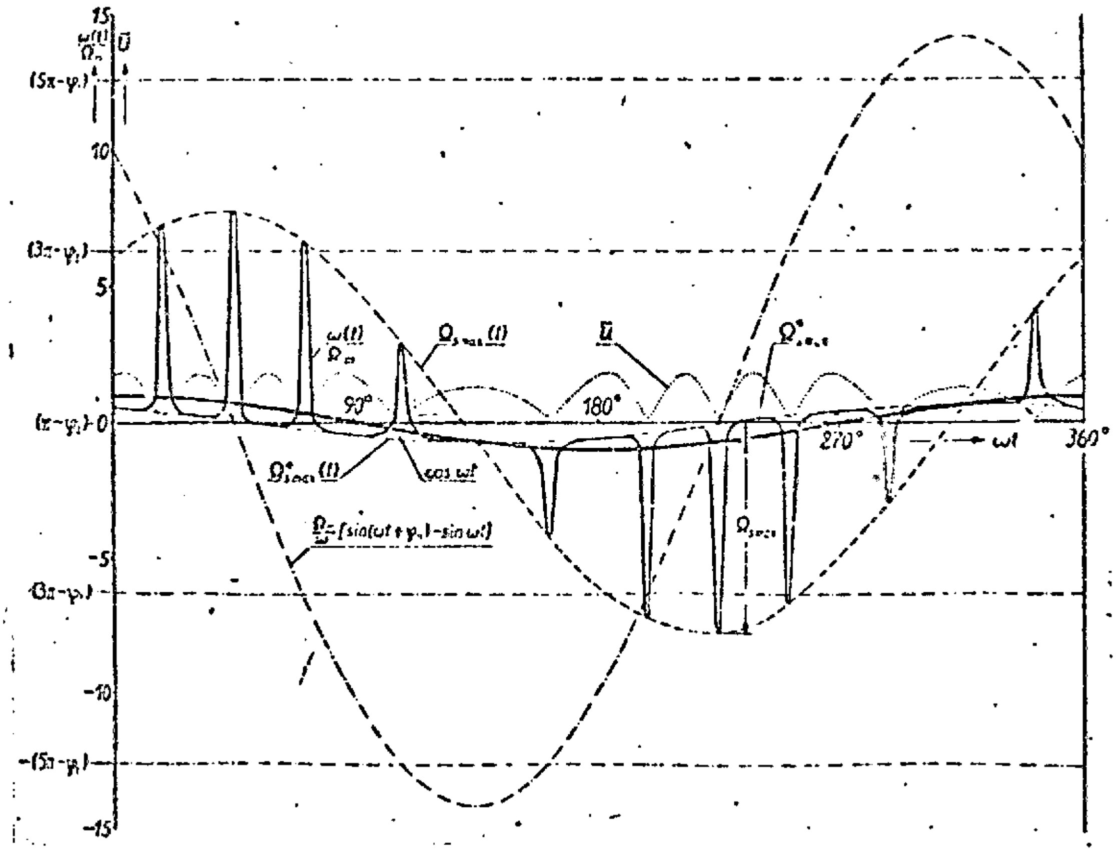

Fig. 5. Frequency course over time with the superimposition of two frequency-modulated oscillations.

$\varphi_t = 180^\circ$; $\varphi_n = 90^\circ$; $A = 0{,}833$; $\Phi_m = 10$

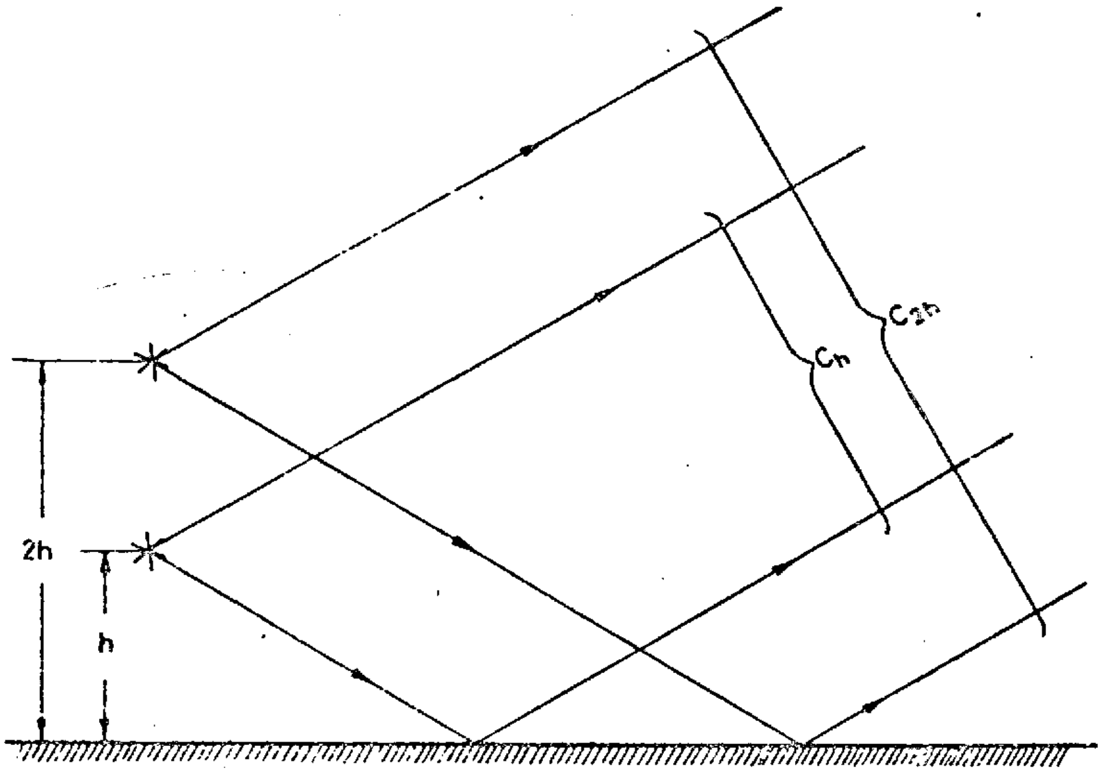

Fig. 6. Superimposition of direct radiation and radiation reflected from the ground for the formation of the course diagram C_h and C_{2h} of the glide path antennae, with the antenna center of gravity heights h and 2h.

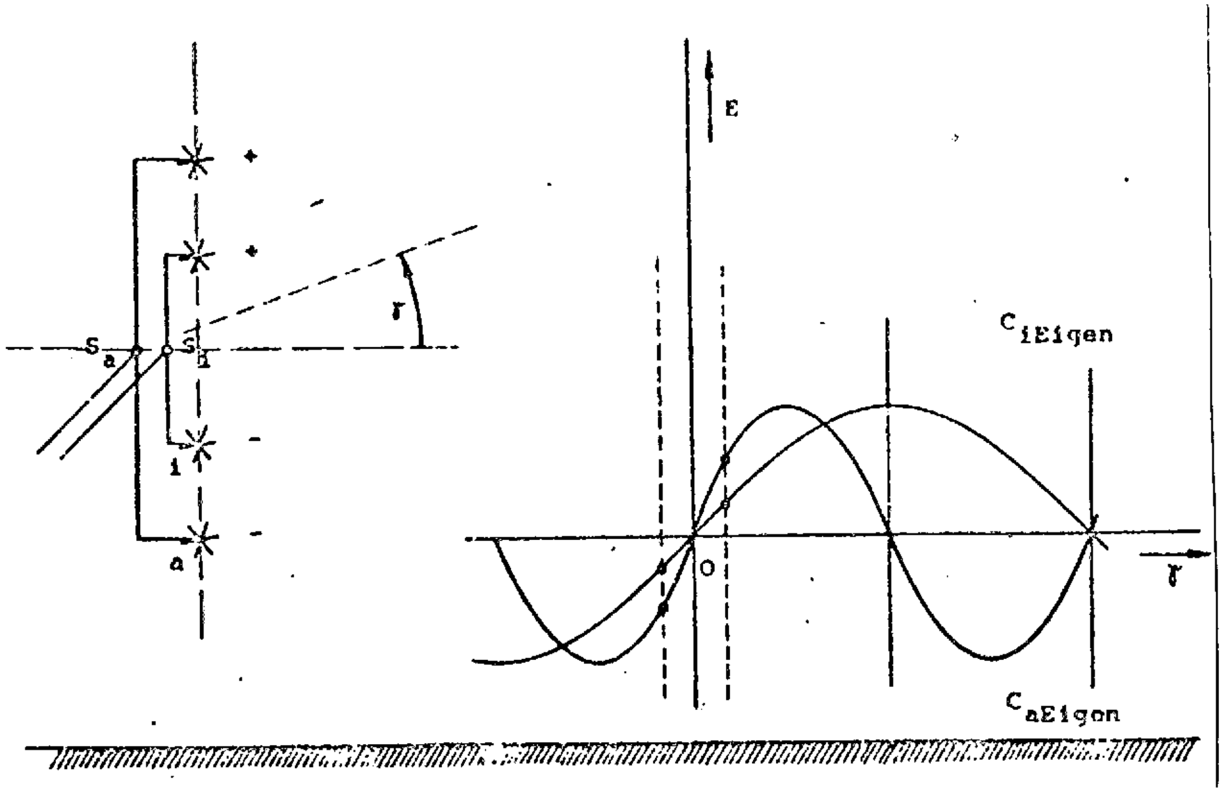

Fig. 7. Outer (a) and inner (i) dipole pairs with common center of gravity.

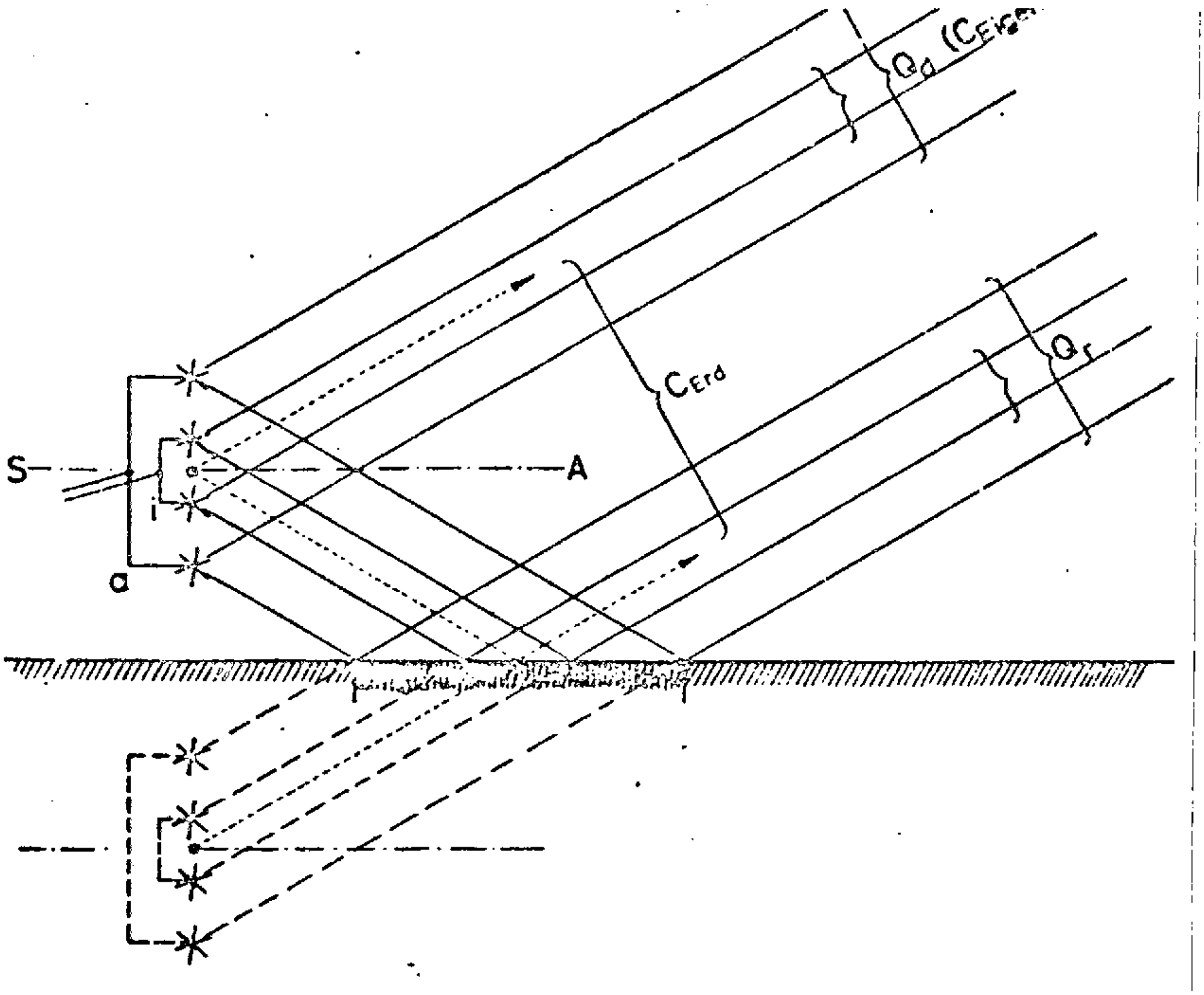

Fig. 8. Quotient formation for direct Q_d and reflected Q_r waves.

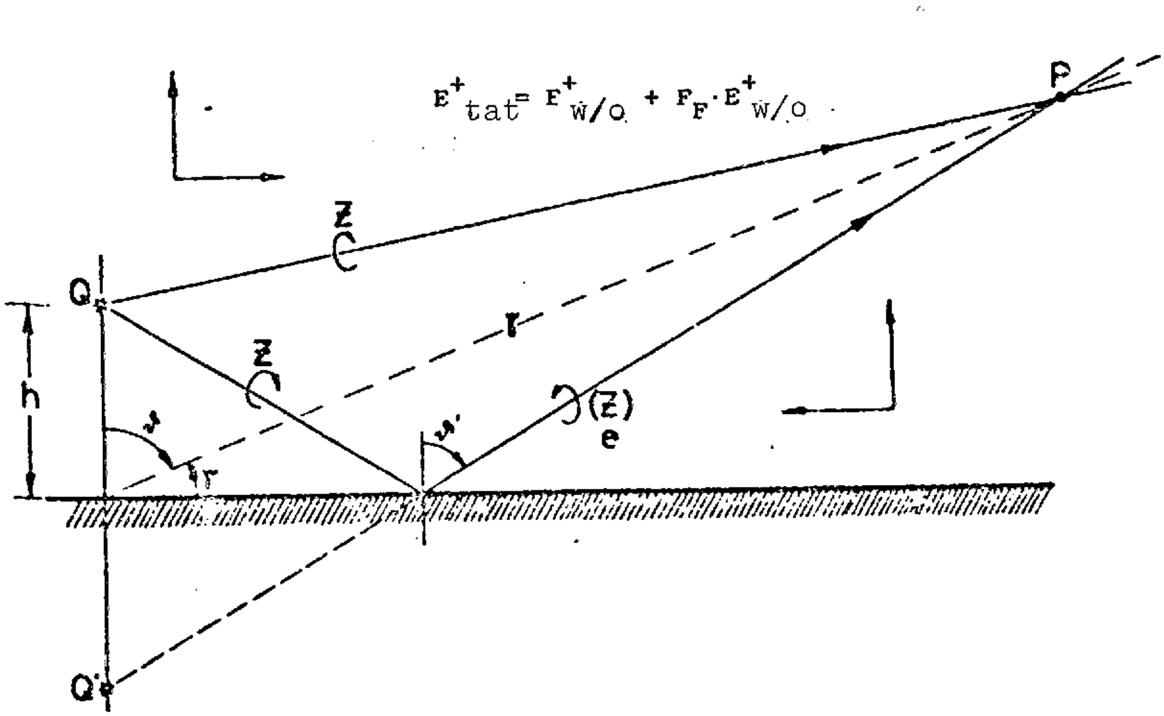

Fig. 9. Reversal of the direction of rotation of the wave reflected from the ground with circular polarization.

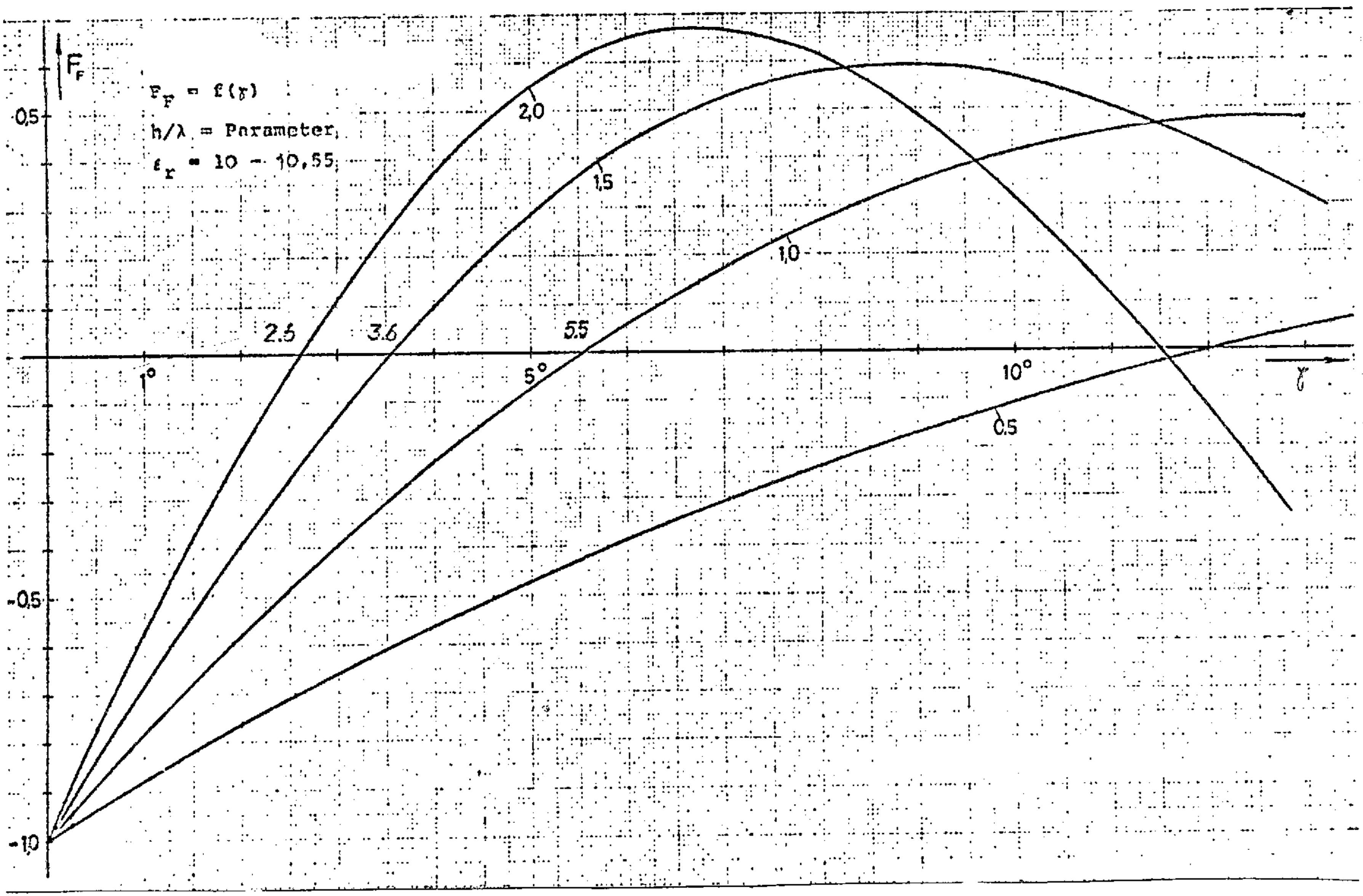

Fig. 10. Field amplitude error.

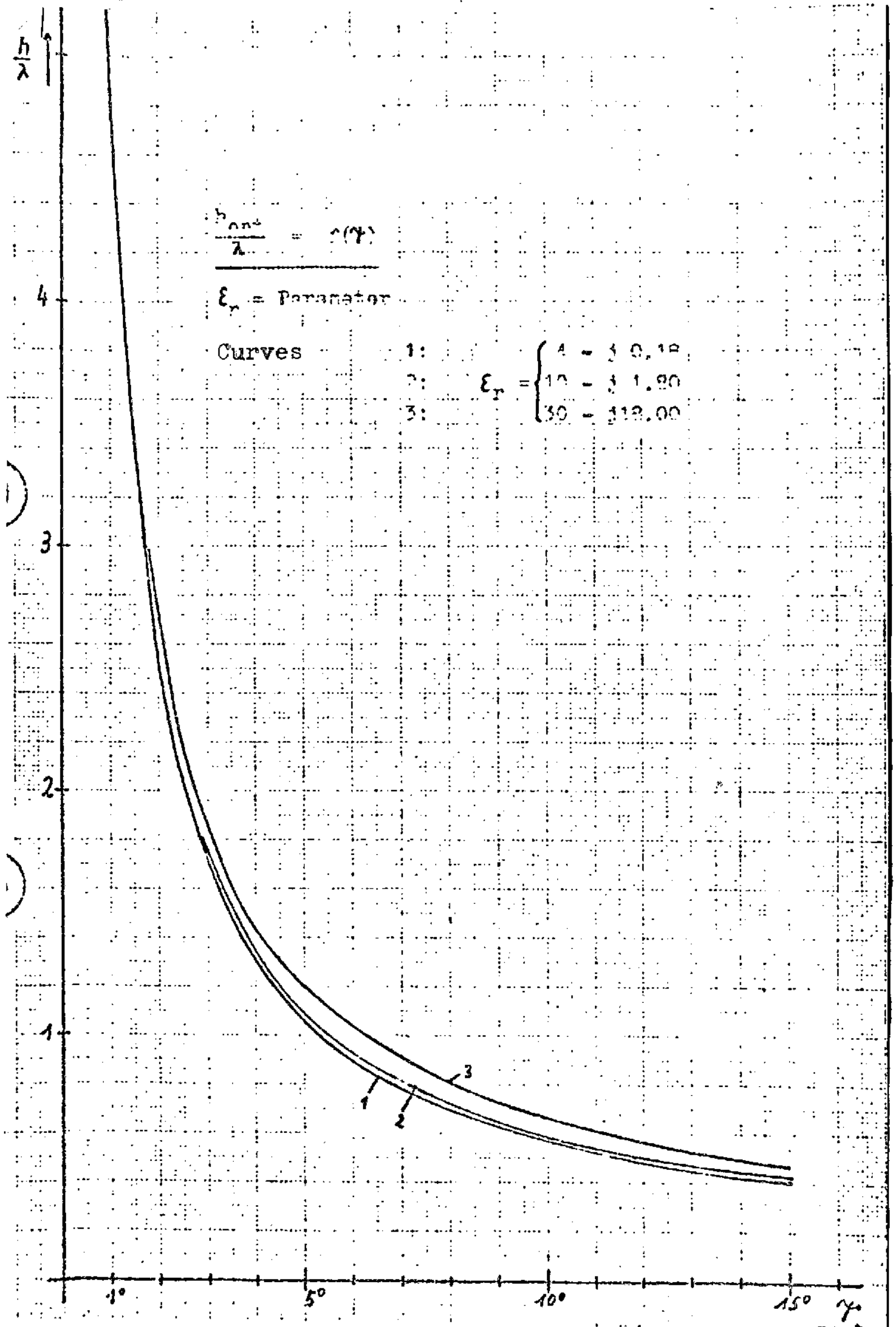

Fig. 11. Optimum height of the spherical radiator.